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ATEC Initiatives in Response to the Office of the Secretary of Defense Policy Guidelines for Test and Evaluation

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The Army Test and Evaluation Command (ATEC) is using mission-based test and evaluation (T&E), among other initiatives, to implement the Department of Defense T&E guidelines. Mission-based T&E focuses on the identification and alignment of system components and functions with the tactical missions and warfighting functions/tasks that the system supports. The approach facilitates testing in an "operationally realistic" environment and evaluating "in the mission context at the time of fielding." Further, it facilitates the assessment of system functionality, the assessment of the effect of system functionality on operational capability, and the assessment of the capability of the warfighter to accomplish mission tasks.

Key words: Capabilities and limitations assessment; data management & documentation; early test; experimental design; integrated DT and OT; mission-based T&E; operational realism; typical user.

Section 231 of the National Defense Authorization Act for Fiscal Year 2007 directed a review, and amendment, if necessary, of defense acquisition test and evaluation (T&E) policies and practices. In response to Section 231, the Office of the Deputy Under Secretary of Defense for Acquisition, Technology and Logistics (USD [AT&L]) produced a Department of Defense (DoD) Report to Congress on Policies and Practices for Test and Evaluation, dated July 17, 2007, in order to satisfy this legal mandate. This report discussed eight key T&E principles.

The intent of this article is to describe how the U.S. Army Test and Evaluation Command (ATEC) is implementing these eight principles. The principles along with ATEC initiatives for implementing the principles are provided in *Table 1*.

The first of these principles encourages the T&E community to broaden its focus away from pass/fail, final milestone decision-oriented assessments. It suggests providing periodic assessments to the materiel developer with emphasis on progress made versus requirements met/not met. This method had been successfully applied in support of the Ballistic Missile Defense System and Future Combat Systems programs. A similar approach is used for Rapid Acquisition Program Systems, where capabilities and limitations assessment reports are updated every 6 months with highlights of the ongoing T&E efforts.

The second principle attests to the value of very early test events to obtain initial insights into the strengths and weaknesses of early design concepts. It also implies that more emphasis on early experimental design for these test/experimentation events should result in testers being able to more efficiently gather information on system performance. The increased analytical rigor that design of experiments brings should result in better early estimates of system performance and potential.

The ultimate goal of integrated testing is to ensure that all stake holders (Program Manager [PM], developmental testers, operational testers, and evaluators) collaborate so that all can use the data from any test event to satisfy their needs. There are complicating factors, which make fully attaining this goal difficult; for example, developmental testing (DT) is characterized by the use of a "test-fix-test" process, which allows the system design to constantly be improved and refined; final operational testing (OT) is usually conducted with systems that are nearly fully mature and are "production representative." However, we have made great strides in approaching this goal over the last several months. Many more DT events are being conducted with what we refer to as more "operational flavor." Soldiers are participating in many

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Table 1. How to achieve the Office of the Secretary of Defense policy guidelines.

Principle	How to Implement
Measure improvements to mission capability and operational support.	Conduct periodic or annual assessments of observed levels of improvement. Each assessment becomes the "rolling baseline" for the last.
Experiment to learn strengths, weaknesses, and the effect on operational capabilities.	Increased emphasis on DT/OT experimental design: test under controlled conditions to determine capabilities and limitations.
Integrate DT and OT.	Consider using a single test event to address both DT/OT T&E requirements. Use an OT experimental design during DT. Give DT an operational flavor with appropriate threats and Soldier operators.
Begin early, be operationally realistic, and continue throughout the life cycle.	Get involved very early in the development process. Liaison with the PM and contractors. Coordinate and assist the combat developer in developing requirements and rationale.
Evaluate in the mission context expected at the time of fielding.	Ensure an operational environment with realistic and representative threats that are expected at the time of fielding plus 5 years. Apply a "mission-based test and evaluation" (MBT&E) focus to the system evaluation.
Compare to current mission capabilities.	Whenever possible, include in the OT experimental design a comparison to the baseline system. Factors such as terrain, mission, operational mode summary and mission profile (OMS/MP), and tactics, techniques, and procedures (TTP) must be held constant between the current system and the system under development. A model-test-model approach may provide the best estimates of system comparison.
Use all available data and information.	Develop a data management strategy and define the data early. Use any credible data source: historical data as well as data from contractor testing, DT, Mod/Sim, etc. for system evaluation. Data must be properly managed and documented (using a data model) to facilitate understanding of differing sources of like data.
Exploit benefits of Modeling and Simulation	Supplement/complement live testing with virtual and constructive simulations. Plan for early verification, validation, and accreditation of models and resource the effort.

DT events either as observer subject matter experts (SMEs) or as system operators if safety constraints allow.

Early involvement of the T&E community in system development has many potential benefits. This allows the Army Evaluation Center (AEC), for example, to provide the data requirements to testers early on, so they can structure test events to satisfy OT as well as DT evaluation requirements. Some benefits that we have seen include the following:

- contributions in drafting the T&E portions of the system specifications,
- technical support for the source selection process,
- assistance in the development of more realistic requirements,
- improved contractor understanding of requirements,
- more informed and balanced assessment reports,
- problems identified earlier and fixed more economically, and
- a much more timely developmental process.

The Stryker program is an excellent example of the efficiencies gained through early involvement. Hundreds of improvements were identified and fixed during an extensive, early T&E program for the initial eight Stryker variants. The system was developed and fielded quickly and in record time.

Evaluating in a mission context has many benefits. In the past, evaluation products have frequently highlighted technical performance requirements that have not been achieved. The senior decision maker "so what" question that sometimes has proven difficult to answer is "What are the operational mission impacts of not meeting these requirements?" To facilitate being able to address this question and others, ATEC has adopted a new mission-based T&E (MBT&E) methodology for all its programs.

We do not always have the resources to conduct a live test in which the system under test is compared with the baseline system. Also, controlling some factors and conditions (level of unit training, different leadership styles, limited sample sizes, learning effects, etc.) for such events makes them difficult to execute and analyze. ATEC has adopted a "model-test-model" approach as a preferred evaluation strategy for many of these types of system tests.

Traditionally, ATEC has always endeavored to use all possible data sources in system evaluation. Utility of some of these data has been improved by closer, early coordination between the contractor and the T&E community. Adoption of common data definitions is a new initiative, which will greatly facilitate the utility of this data exchange.

The utility of modeling and simulation (Mod/Sim) in support of the T&E process has expanded markedly. Mod/Sim has been used effectively as a "wrap-around" to simulate large, joint forces for major tests. Mod/Sim tools have extended specialty analysis areas such as survivability; reliability, availability, and maintainability (RAM); and integrated logistic support (ILS). Force-on-force models have been used to augment and extend system assessments. This is a large growth area for T&E.

Acceptance of these principles has prompted areas of increased emphasis and several new T&E process innovations. The rest of this article focuses on four of the above-mentioned initiatives: MBT&E, experimental design, data management and documentation, and integrating developmental and operational testing. These best practices are essential to improving our strategy for system evaluation and to enabling the identification, definition, structuring, and prudent resourcing of the areas of study and the data needed to test and evaluate an Army system. ATEC System Teams (ASTs) responsible for the T&E of Army systems address these initiatives in their T&E plans.

MBT&E

MBT&E is a methodology that seeks to assess the "strengths and weaknesses" of a system and its components and "the effect on operational capabilities." Purposes and requirements for the methodology were derived from recent T&E policy-shaping initiatives such as the initiatives shown in *Table 1*. The overall development of MBT&E has been done using an interagency working group that assessed individual mission-based concepts, developed a combined methodology from these concepts and from T&E policy requirements, coordinated the methodology with organizations throughout the acquisition community, executed pilot projects, and incorporated comments and lessons-learned from the coordination and execution efforts. The result is a baseline MBT&E methodology that was published in January 2009 and is in use to develop ATEC T&E strategies today. Continuing methodology development is leading to improved efficiencies and synchronization of the efforts of the Services' Operational Test Agencies (OTAs) and the Director, Operational Test and Evaluation (DOT&E).

MBT&E consists of a framework and a procedure. The MBT&E framework is composed of four main elements: mission, system, evaluation, and test. The methodology links the information in these elements to create a T&E strategy that associates the functionalities a system must possess with the warfighting functionalities/capabilities it must support. Further, it identifies the associated T&E measures and standards, operational conditions, and the data required to support the evaluation. The MBT&E procedure is a step-by-step description of activities that guide the development and execution of the T&E strategy. It describes the activities for the following:

- analyzing unit missions and tasks,
- analyzing the materiel system of systems components and functionality,
- developing T&E measures and data sources,
- executing the evaluation,
- and reporting of unit and system effectiveness, suitability and survivability.

The framework and procedure provide a method to conduct the following:

- planning of integrated and synergistic T&E requirements,
- continuous evaluation from program inception through deployment, and
- evaluation simultaneously focused on system performance and warfighter capabilities in the mission context.

Table 2 shows an example of the MBT&E framework applied to an unmanned aerial system (UAS) unit conducting an attack by fire mission. The mission is broken down into three "phases": (a) conduct reconnaissance, (b) direct attack, and (c) indirect attack. Each phase is further broken down by the unit tasks necessary to accomplish the mission. The mission, phases, and associated unit tasks are shown in the column headings. The system components and functions are shown in the row headings. The system functions are linked to the tasks by the addition of an evaluation measure in the intersecting box in the table. The operational context of the task is applied to the system functions through these linkages and is used to

Table 2. Mission-based test and evaluation (MBT&E) framework example—unmanned aerial system.

UAS: Unmanned Aerial System OM: Operational Measure TM: Technical Measure			MISSION/TASKS					
			Attack by Fire (ART 7.5.1)					
			Conduct Reconnaissance			Direct Attack		Indirect Target
SYSTEM COMPONENT		**SYSTEM FUNCTION**	Arrive in Area of Operations (AO)	Detect & Locate Surface Targets (ART 3.2)	Intel Support to Targeting (ART 2.4.1)	Lethal Direct Fire Against Surface Target (ART 2.4.1)	Provide Fire Support (ART 3.3)	2.3.2 Indirect Fire, Surface-to-Surface (ART 3.3.1.1)
UAS	Airframe	Navigate to AO	- Time to Arrival in AO - Navigation Accuracy					
		Execute search pattern	- Time on Station					
	Communication Equipment	Send call for fires					- % Fire Calls Sent/ Received	
	Sensor	Detect target		- % Targets Detected - Detection Range				
		Locate target		- Location Accuracy				
		Identify target			- % Targets Identified			
	Laser Designator	Designate Target				- % Targets Hit - Spot Jitter		
	Missile	Destroy Target				- % Targets Killed		
M109 Paladin	Communication Equipment	Receive Firing Order					- Time to Process Fire Order	
	Firing System	Fire Round						- % Targets Killed

develop the operational conditions addressed in the measure. This example illustrates the design of a system of systems evaluation by looking at the performance of the UAS to conduct a direct attack and to support an indirect attack using a M109 Paladin. It also illustrates the use of tasks in the Army Universal Task List to provide a doctrinal reference and help establish measures and standards used in the evaluation.

The achievement of an integrated MBT&E strategy comes with the analysis of data sources to support the evaluation of the measures. *Table 3* shows the measures from *Table 2* and the linkages to all possible data sources. Possible data sources include contractor tests, Mod/Sim, hardware-in-the-loop, and interoperability certification. Integrated use of the data is achieved by identifying the right type of data at the right time in the development program. Synergistic use of the data is achieved by combining the data from more than one source into an "accumulated" knowledge of system and task performance.

The execution of the MBT&E pilot projects and ongoing implementation of the MBT&E methodology within ATEC have yielded a long list of lessons learned and observations. Lessons learned are being applied to improve the development and robustness of MBT&E strategies. Some key observations include the following:

- Impact of system performance on mission task is being achieved.
- Task context is critical to designing integrated T&E and enabling more operationally relevant developmental test.
- Improved efficiencies and aligning of expectations are achieved by combat and materiel developer participation in the MBT&E process.
- MBT&E is similar to the processes used by the U.S. Navy's Operational Test and Evaluation Force, and the U.S. Air Force's Operational Test and Evaluation Center.

The last observation has led to an effort within the Services' OTAs and DOT&E to develop a common

Table 3. MBT&E framework example—measure to data source linkages.

MEASURE	DATA SOURCE: Contractor Tests	Modeling & Simulation	Interoperability Testing	Hardware-In-The-Loop	DT Flight Tests	Operational Tests
UAS Time to Arrive in Area of Operations					x	x
UAS Time on Station	x					x
UAS % Targets Detected					x	x
UAS % Targets Identified					x	x
UAS % Targets Hit		x			x	x
UAS % Targets Killed		x				
M109 Paladin % Targets Killed		x				
M109 Paladin Time to Process Fire Order			x			x
UAS Navigation Accuracy	x					
UAS Sensor Detection Range				x	x	
UAS Target Location Accuracy					x	
% Fire Calls Sent and Received			x			

process with the goals of synchronizing processes, products, and training; and enhancing Joint Services operational testing.

Experimental design

A statement of the problem facing our analysts is essentially this: Given ever increasing resource constraints, assess to the extent possible the effectiveness of an Army system under the full range of operational conditions within which it is intended to operate. In ATEC, we are dealing with this problem by placing greater emphasis on formal experimental designs versus reliance, sometimes on less structured or short "free-play" demonstrations. Experimental designs permit a rigorous structuring of test events such that the full range of operational conditions can be addressed while conserving resources. Moreover, the use of experimental designs to structure test events allows the evaluator to assess from "improvement to mission capability and operational support," to "learn strengths, weaknesses, and the effect on operational capabilities"; and to make comparisons "to current mission capabilities." Tools and procedures used to structure test events include factorial designs, fractional factorial designs, sample sizing, and statistical analysis.

Experimental designs are represented during early command reviews of the evaluation strategy using a matrix showing how the factors and conditions are combined. An important step in getting to the matrix

Table 4. Factors and conditions table template.

Factor (F)	Control	Conditions (C)
F_1	Control Type	$C_1 \ldots C_J$
F_2	Control Type	$C_1 \ldots C_K$
F_3	Control Type	$C_1 \ldots C_L$
.	.	.
.	.	.
.	.	.
F_N	Control Type	$C_1 \ldots C.$

is a factors and conditions table. In this table, each factor, the conditions the factor may assume, and the method of controlling the factor is given.

Factors may be systematically varied, uncontrolled, "tactically" varied, or held constant. Tactically varied factors are changed in accordance with unit tactics, techniques, and procedures and have the same status as uncontrolled factors, unless incorporated into the test design.[1] An experimental design requires that at least one factor is systematically varied. If all of the factors in the table are tactically varied (and not incorporated into a test design) or are uncontrolled, it may be very difficult to explain why a system performed well or performed poorly.

Analysts prepare a factors and conditions table and a matrix early in the planning process. A factors and conditions table template is given in *Table 4*. An example is provided in *Table 5*. The system represented in *Table 5* is the Global Position System (GPS) Guided Fuze. Four factors (weapon, temperature, quadrant angle, and munitions) are systematically varied, two factors (range and mission-oriented protective posture [MOPP]) are held constant, and one factor (weather) is uncontrolled. Given the controlled factors, an experimenter could assess the effects of the varied factors on delivery accuracy. The factors and conditions given in *Table 5* are represented in a matrix as a full factorial design in *Table 6* and as a fractional factorial design in *Table 7*. Fractional factorial designs can enable savings in the total number of test executions without giving up any information about the effects of the factors and their first-order interactions. As shown in *Table 7*, there is a 33 percent (12/36) reduction in the number of rounds required to assess the effects of the four systematically varied factors on accuracy. In these examples, each combination of conditions is executed five times to help ensure test conditions are representative.

The use of experimental designs to structure test events allows the evaluator to assess the effects of the full range of operational conditions on evaluation measures, assess improvements to mission capability

Table 5. Global Position System (GPS) Guided Fuze system factors and conditions table.

Factor	Control	Conditions
Weapon	Systematically Varied	M109A6, M777A2*
Temperature	Systematically Varied	Hot, Ambient, Cold
Quadrant Angle	Systematically Varied	High, Low
Munitions	Systematically Varied	M795, M549, M107
Range	Held Constant	90% of maximum
MOPP	Held Constant	MOPP 0
Weather	Uncontrolled	

* The M109A6 is the 155mm self-propelled howitzer known as Paladin; the M777 is a towed lightweight 155mm howitzer.

and operational support, make comparisons to currently fielded equipment, and conserve limited resources.

Data documentation

AEC must be able to communicate their data requirements to the tester; design and create data sets that can be used to analyze the data received from the tester; and ultimately, archive that data that can be used for accrediting models and simulations and future comparative analysis. The role of the system evaluator within the AST is critical. They must ultimately decide what data are needed, how to get that data, and what the source of that data is.

ASTs must also be able to use data from all sources. They must be able to use data from past assessments in order to measure improvements in functionality and operational capabilities. They must also be able to use contractor data and DT data in order to identify deficiencies early in the development process. The crucial first step toward accomplishing these goals is to properly manage the data requirements identified during the requirements analysis.

Well-managed data are visible, accessible, and understandable. Data are made visible if they are properly tagged with descriptors. The DoD Discovery Metadata Specifications can be used to help accomplish making data visible. Data are accessible if they are held in a common area and can be searched and retrieved by the members of the interested community. Data are made understandable through precise, well-formed definitions documented in a data dictionary.

Currently, increased emphasis is being placed on making data understandable. Analysts in AEC are asked to follow naming and defining conventions when developing data dictionaries.[2–4] In the data dictionaries, the analysts name and define the objects and events

Table 6. Global Position System (GPS) Guided Fuze system full factorial design.

Temperature	Weapon Type	Quadrant Angle High			Quadrant Angle Low		
		M795	M549	M107	M795	M549	M107
Hot	M109A6	5	5	5	5	5	5
Hot	M777A2	5	5	5	5	5	5
Ambient	M109A6	5	5	5	5	5	5
Ambient	M777A2	5	5	5	5	5	5
Cold	M109A6	5	5	5	5	5	5
Cold	M777A2	5	5	5	5	5	5

Table 7. Global Position System (GPS) Guided Fuze system fractional factorial design.

Temperature	Weapon Type	Quadrant Angle High			Quadrant Angle Low		
		M795	M549	M107	M795	M549	M107
Hot	M109A6	5		5	5	5	
Hot	M777A2	5	5		5		5
Ambient	M109A6	5	5			5	5
Ambient	M777A2		5	5	5	5	
Cold	M109A6		5	5	5		5
Cold	M777A2	5		5		5	5

being studied (e.g., unit, mission, task, sensor type), and name and define the data elements (e.g., unit identifier, mission date-time, task outcome code, sensor type name) used to describe the objects and events under study.

AEC must be able to communicate data requirements to the tester, use the data received from the tester, and archive data for future use. ASTs must also be able to use data from diverse sources including historical data and contractor data. This is made possible if data are understandable and are documented in a data dictionary that is shared throughout the test and combat and materiel development communities.

Combined and integrated DT and OT

Combining or integrating DT and OT is becoming more and more necessary in order to address the greatest number of evaluation questions with the least use of limited T&E resources. Combined DT and OT describe a single test event that produces data to answer both developmental and operational system issues and is usually conducted as a series of distinct DT and OT phases. Integrated DT and OT describe a single-phased event that generates data to address developmental and operational issues simultaneously under operational conditions. Integrated DT and OT have the potential to answer both DT and OT issues more efficiently in terms of the time and resources normally required by separate tests. It is also the most difficult type of testing to execute as it requires maximum coordination and cooperation among all members of the test community. AEC analysts are required to consider integrating DT/OT in the evaluation strategy while considering the following guidelines:

- Fully consider all safety issues.
- Achieve maximum cooperation among test team(s).
- Consider use of highly experienced, soldier SMEs for early test events.
- Consider use of typical user soldiers for later test events.
- Enhance operational realism of DT events, whenever possible.
- Use a single experimental design to answer both DT and OT questions.

Currently, the most acceptable form of integrating DT and OT is to enhance the operational realism of the DT. This is usually done by considering realistic threats and observing operational conditions and scenarios specified in the Operational Mode Summary/Mission Profile. Sometimes imparting a realistic operational "flavor" to a test is relatively easy. One example would be the varying of message load when testing interoperability between two communication systems. Imparting a realistic operational "flavor" can also be difficult. For example, the required use of soldier operators requires a safety release that may not be available during DT.

A question will always arise as to whether the conditions under which testing occurs are sufficiently operational to permit the use of data generated at a DT event to answer operational issues. The AST will make this judgment. If a single-phased event cannot be used to generate data to address developmental and operational issues simultaneously under operational conditions, a combined event with distinct DT and OT phases can be implemented. Conducting DT with deference to operational realism followed by an operational phase may be much easier to execute.

An experimental design must be used if the goal of testing is to predict how a system will perform under different conditions. An experimental design that accommodates the needs of the developmental tester and operational tester must be used for integrated testing. In contrast, combined DT/OT can employ separate experimental designs for the different DT and OT phases.

Summary

The eight OSD guidelines introduced in the 2007 DoD Report to Congress on Policies and Practices for Test and Evaluation provide a basis to better fulfill the key objectives of Defense acquisition: to acquire quality products that satisfy user needs, to do so with measurable improvements to mission capability and operational support, to accomplish this in a timely manner, and to ensure purchase at a fair and reasonable price. AEC has undertaken to implement these principles by introducing the initiatives in *Table 1*. The initiatives include MBT&E, experimental design, data documentation, and integrating DT and OT. These best practices are essential to our evaluation strategy. They enable the identification, definition, structuring, and efficient resourcing of the areas of study and the data needed to test and evaluate an Army system and are addressed by ASTs early in the planning process. ❑

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Endnotes

[1]The stimulus for a unit to tactically vary comes from some external change in the test unit's physical or tactical environment. If the conditions resulting in a tactical change are made part of the test design, there will be start and finish times for the conditions assumed for a tactically varied factor. Data collected between the start and finish time for a specific condition will have had that condition held constant.

[2]International Organization for Standardization and International Electrotechnical Commission (ISO/IEC) international standard 11179 - *Metadata registries (MDR)*.

[3]DOD Directive 8320.02 Data Sharing in a Net-Centric Department of Defense, April 23, 2007.

[4]DOD 8320.02-G Guidance for implementing Net-Centric Data Sharing, April 12, 2006.